THE EFFECT OF HERBICIDES ON SOIL MICRO-ORGANISMS

W.W. Fletcher
Department of Applied Microbiology and Biology,
University of Strathclyde, George Street, Glasgow, C.1.

INTRODUCTION

A symposium on "Herbicides and the Soil" was held at Oxford, in 1960, and the four papers read at the symposium were subsequently published. One of these papers by the present author, (Fletcher, 1960), on "The effect of herbicides on soil micro-organisms" reviewed the work on this topic up till 1959; it included some 260 references. The present paper may be looked upon as an addition to the original paper and covers the years 1960 - 1965; for a broad coverage of the field both papers should be read together. It is hoped that most major papers on the subject have been included. Some, because of language difficulties have not been read in the original and in such cases the present author has leaned heavily on "Weed Abstracts".

The importance of soil micro-organisms in maintaining the fertility of the soil has been stressed many times. So too has the importance of ensuring that herbicides should not interfere with the manifold activities of these organisms. This has been sufficient justification for research in this field. There is however, another factor; it is that the study of the mechanisms of activity of herbicides in micro-organisms may give a lead into how they act on higher plants. At least one example of this type of investigation is included in the present review.

In their papers authors differ in the expression of quantities used during their experiments. Thus some have used molar quantities, some parts per million, some percentages, some kilograms per hectare and some pounds per acre. In order to make comparisons possible, while at the same time retaining the authors own figures I have included in parenthesis the corresponding amount in parts per million after each molar solution or percentage. It has been difficult from some papers to determine whether the stated amounts relate to acids or salts so that the calculated parts per million should be regarded merely as approximate. For the sake of simplicity kilograms per hectare and pounds per acre may be regarded as equivalent (in fact 1 kg per hectare = 2.2 lb per 2.5 acres). Relating pounds per acre to parts per million is a more difficult task. A rough approximation would be 2 - 2.5 ppm = 1 lb per acre (Fletcher 1960).

The classification of the herbicides is taken from Weed Control Handbook (Woodford and Evans, 1965). Herbicides that have been reviewed in the previous publication (Fletcher 1960) are:-
INORGANIC CHEMICALS: Ammonium sulphamate, calcium cyanamide, sodium arsenite, sodium-tetraborate decahydrate, sodium chlorate, sulphuric acid.
AUXINS AND CLOSELY RELATED COMPOUNDS: Phenoxyacetic Acids: MCPA, 2,4-D, 2,4,5-T. Phenoxypropionic Acids: 2,4,5-TP. Phenoxybutyric Acids: MCPB, 2,4-DB. Phenoxyethyl sulphate and related compounds: 2,4,-DES, 2,4-DEB, 2,4,5-TES.
OTHER SYNTHETIC GROWTH REGULATORS: NPA.
HALOGENATED ALIPHATIC ACIDS: TCA, Dalapon.
CARBAMATES: Propham, chlorpropham, CDEC.
ACETAMIDES: CDEA, CDAA.
SUBSTITUTED UREAS: DCU, Monuron.
SUBSTITUTED PHENOLS: DNOC, Dinoseb, PCP.
MISCELLANEOUS: Amino-triazole, endothal, maleic hydrazide.
SURFACE ACTIVE AGENTS AND EMULSIFIERS.

PHENOLS (contact herbicides).

(a) DNOC (2-methyl-4,6-dinitrophenol). Selective weedkiller. Doses vary between 4 and 10 lb per acre with normal volume rates 80-100 gallons per acre.

(b) Dinoseb (2-(1-methylpropyl)-4,6-dinitrophenol).
Annual weed control in peas and to a lesser extent in seedling lucerne and undersown cereals. Dose 1-3 lb per acre. Medium high volume spray.

DNOC

Corke & Robinson (1960) and Voderberg (1961) both find that DNOC applied at field rates has no adverse effect on the soil micro-flora. Jensen (1964b) has found that under acid conditions (pH 4.8 - 5.1) carbon dioxide evolution is markedly inhibited for at least 8 days at concentrations of 100 ppm and to a lesser extent for five days by 10 ppm. If however the soil pH was raised to 6.6 there was no inhibition (except for an initial inhibition at 100 ppm. This was followed by a rapid recovery). Jensen attributes the inhibition at the low pH to dissociation. DNOC with pK of 4.4 is almost completely dissociated in neutral soil but 20% remains undissociated at pH 5.0. He also found similar results for dinoseb.

Doses of 10 - 150 ppm DNOC has in neutral and mildly alkaline soil within a week at 25°C a consistently stimulating effect that amounts to approximately 10 - 30% above the carbon dioxide from control soil. Jensen considers that the stimulating effect is complex. One contributory cause is presumably the increased respiration due to suppression of assimilatory processes through uncoupling of oxidative phosphorylation. When a temporary inhibition precedes the stimulation it is possibly the result of a mild partial sterilization due to the microbicidic properties of the nitrophenolic compounds, followed by the arising of a new population of young and metabolically active micro-organisms resistant to the DNOC. The amounts of carbon dioxide that could have arisen by quantitative oxidation of the DNOC were too small to account for the observed stimulations.

NITRILES

(a) Ioxynil (4-hydroxy-3,5-di-iodobenzonitrile).

(b) Bromoxynil (3,5-dibromo-4-hydroxybenzonitrile).
For control of broad leaved weeds in cereals. Dose 3 - 12 oz per acre.

Ioxynil and Bromoxynil

Smith and Fletcher (1964) have looked at the effect of bromoxynil and ioxynil on a range of soil micro-organisms. They conclude that although both of these chemicals are fairly inhibitory to fungi and bacteria at low concentrations, these concentrations are far in excess of what are likely to be found in soil. In general ioxynil is more toxic than bromoxynil.

PHENOXYACETIC ACIDS

(a) MCPA (4-chloro-2-methylphenoxyacetic acid).

(b) 2,4-D (2,4-dichlorophenoxyacetic acid).
Selective translocated herbicides. Dose 4 - 32 oz per acre.

(c) 2,4,5-T Most important application is for killing woody plants.

PHENOXYBUTYRIC ACIDS

(a) MCPB (4-(4-chloro-2-methylphenoxy) butyric acid).

(b) 2,4-DB (4-(2,4-dichlorophenoxy) butyric acid).

(c) 2,4,5-TB (4-(2,4,5-trichlorophenoxy) butyric acid).
Active through their conversion to the corresponding phenoxyacetic acids by plants possessing the appropriate β-oxidising enzyme system. Dose 24-48 oz per acre.

SUBSTITUTED PHENOXY ACIDS

There is general agreement that at the rates used in agricultural practice the phenoxyacetic, phenoxy-propionic and phenoxybutyric acids have no harmful effect on the soil microflora (Fernandes 1957; Virag 1959; Lenhard 1959; Mitzkovski

1959; Shklyar et al 1959; Shklyar et al 1961; Voderberg 1961).

An interesting finding by Mitzkovski (1959) is that although 2,4-D and MCPA applied in the usual doses have no harmful effect on the soil microflora they do adversely affect the epiphytal microflora of sprayed plants (particularly dicotyledons).

There are a number of reports that MCPA + 2,4-D may stimulate the growth of micro-organisms. Durkhanin and Kolosova (1962) demonstrated that in laboratory experiments 2,4-D at 3 kg/ha applied broadcast to sandy dernopodzolic and chernozem soils doubled or trebled the nitrate content two and a half months after application and also increased the mobile phosphorus. Vorober and Abueva (1960) showed that spraying 2,4-D amine increased the number of ammonifiers, nitrifiers and cellulose decomposing micro-organisms in the soil. The mechanism is not clear. Illyin (1961) considers that the inhibition of protozoa in the soil by 2,4-D appears to cause an increase in soil micro-organisms (because of the lack of predatory effects) but this cannot explain the findings by Shennan and Fletcher (1966) and by Smith and Shennan (1966) that some fungi were stimulated by the presence of low concentrations of MCPA in aseptic culture.

Regarding symbiotic associations Morgan and Fletcher (unpublished) using isolated root culture techniques have found that low concentrations (1 ppm) of 2,4-D applied to the cut end of the root causes a marked increase in nodule numbers and nodule volume in Phaseolus vulgaris although this concentration has no effect on the rhizobia themselves. Presumably it is acting as a hormone within the plant root.

Dean and Law (1964) carried out a series of investigations on the action of 2,4-D on Bacterium lactis aerogenes (Aerobacter aerogenes). They found that this organism does not use 2,4-D as a sole source of carbon to any appreciable extent. They looked into the effect of long continued sub-culture of the organism in the presence of 2,4-D. At concentrations of less than 1000 mg/litre 2,4-D had little effect on growth. As the concentration was increased the growth rate declined gradually. Serial sub-culturing in a concentration of 500 ppm resulted in a progressive reduction in the lag phase over a period of 25 sub-cultures from an initial level of about ten hours to a negligible value. The growth rate which had remained constant while the lag phase was falling then began to decrease over the succeeding 91 sub-cultures providing evidence of the limited extent to which adaption to 2,4-D occurred. The authors consider that the progressive diminution of growth may have been due to a slight degree of degradation of 2,4-D to 2,4-dichlorophenol (which is more toxic than 2,4-D to this bacterium).

Shennan and Fletcher (1966) have shown that, at concentrations approximating to field rates of application, the acetic and γ-butyric forms of the common growth-regulating substituted phenoxy acid herbicides are harmless. At higher concentrations (above 500 ppm) however the γ-butyric acids were found to be toxic to a wide range of micro-organisms including algae, whereas the acetic acids had little effect on growth.

The reason for the significant difference in fungitoxic activity between the acetic and and γ-butyric acid homologues is not immediately apparent. A linear correlation between increase in toxicity and increase in molecular weight does not exist as the intermediate α-propionic acid herbicides (mecoprop, 2,4-DP) are non-toxic acting as α-substituted acetic acids.

The theory of β-oxidation likewise cannot be used to explain the considerable toxidity of the γ-butyric acid molecule since this process infers the breakdown of the aliphatic side chain to the acetic acid. As the α-carbon acetic acid is non-toxic to micro-organisms, the activity of MCPB and 2,4-DB cannot depend directly upon their degradation to the acetic acid.

Part of the reason for the greater toxicity of the phenoxybutyric acids to micro-organisms may be due to the fact that they are much more readily taken up by the micro-organisms. Kirkwood, Robertson and Smith (1966) treated mycelial

discs and extracted mitochondria of Aspergillus niger with 500 ppm solutions of C^{14} carboxy-labelled MCPA and MCPB and the degree of respiratory inhibition was measured over a half hour period. In both discs and mitochondria MCPB was absorbed more rapidly than MCPA and the radioactive content of the various fractions showed a relatively greater uptake of MCPB-C^{14} after a 20 hour period.

Smith and Shennan (1965) have followed this up by attempting to locate the site of action. They extracted mitochondria from A.niger and found that the oxidation of succinate and NADH were inhibited by both compounds though in each case the inhibition by MCPB was much greater than by MCPA. The inhibitory effect of low concentrations of MCPB (5×10^{-4}M = 100 ppm) could be enhanced by prolonged incubation with enzyme preparations. The results of experiments on the effect of the substituted phenoxy acids on the component enzymes of succinate oxidase and NADH oxidase indicate that there are possibly two sites of action of the compounds; one is before the site of action of phenazine methosulphate; the second between the site of action of phenazine methosulphate and methylene blue. They consider that the main site of inhibition is at that part of the respiratory chain which involves ubiquinone, perhaps the enzyme complex ubiquinone reductase, although there may be other minor sites of action before and beyond this point.

BENZOIC AND PHENYLACETIC ACIDS

(a) 2,3,6-TBA (2,3,6-trichlorobenzoic acid). Selective weedkiller at low doses.

(b) Fenac (2,3,6-trichlorophenylacetic acid). Applied to the soil, used extensively in sugar cane for annual weeds and seedling perennials at 2.5 lb per acre. In North America at doses up to 16 lb per acre for control of perennial weeds.

(c) Chloramben (3-amino-2,5-dichlorobenzoic acid). Selective pre-emergence. Dose 2-4 lb per acre.

2,3,6-TBA

Although TBA may initially reduce the microbial activity - in some cases up to 28 days after treatment - there is recovery. (Chandra 1964; Chandra et al 1960).

FENAC

Fenac has no adverse effects at field rates on nitrification and CO_2 production (Corke and Robinson 1960).

CHLORAMBEN

Corke and Robinson (1960) and Ascheman (1963) are in agreement that field rate applications of chlbramben have no effect on the soil microflora (as measured by CO_2 production).

HALOGENATED ALIPHATIC ACIDS

(a) Dalapon (2,2-dichloropropionic acid). Translocated herbicide toxic to grasses and other monocotyledons. Dose 4-40 lb per acre.

DALAPON

Magee and Colmer (1960) have found that concentrations of 50-5000 ppm increases the total number of soil micro-organisms to 264% of control, of actinomycetes to 691%, of moulds to 230% and many of the organisms are capable of using dalapon as the sole carbon source. Four consecutive monthly treatments at the same rate however reduced the total micro-organism number to 63% and the actinomycete number to 53% of that of the controls but at the same time the moulds increased 20 fold and dalapon-users 4 fold.

CARBAMATES

(a) Chlorpropham (isopropyl N-(3-chlorophenyl) carbamate). Normally applied to the soil to prevent establishment of weeds growing from seed. Dose 3-4 lb per acre (propham)
1-2 lb per acre (chlorpropham).

CHLORPROPHAM

At rates used in practice chlorpropham does not inhibit fungi, Azotobacter, butyrate bacteria or aerobic cellulose decomposing bacteria (Shklyar et al 1959).

THIOCARBAMATES

(a) EPTC (S-ethyl NN-dipropylthiolcarbamate).
Active against a wide range of annual and perennial weeds if applied to and incorporated in the soil. Dose 3 - 6 lb per acre.

(b) Di-allate (S-2,3-dichloroallyl NN-di-isopropylthiolcarbamate).
Soil applied for control of wild oats. Dose 1 - 5 lb per acre.

EPTC applied to widely differing soil types at concentrations giving 5 and 100 ppm (the former approximating to field rates), causes a reduced level of activity for at least 28 days but there is great variability according to the soil type and the environmental factors. Microbial activity was estimated by the amount of CO_2 given off. (Chandra et al 1960).

DI-ALLATE

Chandra (1964) looked at the effect of a series of herbicides on the soil microflora. His findings for di-allate are very similar to those for amino-triazole (q.v.) except that at 10 lb per acre the residual effect had gone after 28 weeks.

SUBSTITUTED UREAS

(a) Monuron (N-(4-chlorophenyl)-NN-dimethylurea).
(b) Diuron (N-(3,4-dichlorophenyl)-NN-dimethylurea).
Non-selective at 10-30 lb per acre. At low doses 0.25 - 3 lb per acre may be used selectively in certain horticultural crops.

MONURON

At field rates monuron has no adverse effect on the soil micro-flora. (Corke and Robinson 1960; Shklyar et al 1961). Voderberg (1961) found that 40-200 ppm had no effect on bacteria and fungi. Raud et al (1959) found that it was toxic to a soil alga Stichococcus bacillaris at 10^{-6} (0.1 ppm) in vitro. The addition of glucose or lactose reduced the toxicity.

DIURON

Corke and Robinson (1960) found that diuron had no effect on nitrification and CO_2 evolution at field rates. Chandra et al (1960) and Chandra (1964) report however that at normal rates nitrification was inhibited for 8 weeks but nitrification subsequently occurred. The residual effects in greenhouse conditions had gone by the end of 28 weeks. In the field it lasted longer although even here the effects had gone 52 weeks after treatment.

DIAZINES

Pyrazon (5-amino-4-chloro-2-phenyl-3-pyridazone).
Affects weeds by both foliage and leaf uptake. Most important selective use is in sugar beet. Dose 2-3 lb per acre.

PYRAZON

At 66 ppm (= 200 kg/ha) pyrazon causes a slight increase in soil respiration. Increasing the concentration ten times to 660 ppm slightly reduces respiration. Nitrification is unaffected in muck soils by rates of up to 1000 kg/ha and inhibited in loamy sand, sandy loam and loam soils only by 1000 kg/ha. The above work was done by Jung (1964) and he concludes that the soil micro-flora concerned with CO_2 production and nitrification would be unaffected by the use of pyrazon at normal rates. Pommer (1964) has found that pyrazon at 1000 ppm in culture has no significant effect on the growth of several species of fungi.

TRIAZINES

Affect photosynthesis following uptake by the root system.

(a) Simazine (2-chloro-4,6-bisethylamino-1,3,5-triazine).
(b) Atrazine (2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine).
(c) Propazine (2-chloro-4,6-bisisopropylamino-1,3,5-triazine).
(d) Prometon (4,6-bisisopropylamino-2-methoxy-1,3,5-triazine).
For non-selective control at doses 5-20 lb per acre.

ATRAZINE & SIMAZINE

There is general agreement that at field rates of application atrazine and simazine have no adverse effect on the soil micro-flora nor on nitrification. (Burnside 1959; Corke & Robinson 1960; Ponchon et al 1960; Steinbrennel et al 1960; Guillemat et al 1960; Burnside et al 1961; Voderberg 1961; Eno 1962; Pantos et al 1962; Mashtakov et al 1962; Viragh 1962;)and Guillemat(1960) found that 6 and 300 mg/ha applied to different soil types has no effect on the biological balance of the soil microflora even when a residue of 0.4 mg/litre soil remained in the soil 6 months after application of 6 kg/ha. Klyuchnikov et al (1964) however are exceptional in that they found that 2 kg/ha (the optimal for eradicating annual weeds) atrazine and simazine decreased the numbers of bacteria, fungi and cellulose decomposing micro-organisms in a sandy soil and retarded decomposition of flax tissue added to soil. In light sandy soil 6 kg/ha (the rate required to destroy perennials) atrazine decreased the number of bacteria and inhibited pigmentation in the fungus Trichoderma. The inhibitory effect penetrated to 25-35 cm in sandy soil but the effect of a single treatment was not great and did not inhibit microbial activity significantly.

There are some reports of low concentrations proving to be stimulatory e.g. Gramlich et al (1964) found that 0.5 - 10 ppm atrazine in the presence of sucrose enhances the growth of certain fungi and bacteria.

Kaufman (1964) has shown that both atrazine and simazine (also linuron and diuron) exert significant quantitative and qualitative effects on soil fungus populations. Both chemicals stimulate one or more genera of fungi known to be antagonistic to fusaria. Since certain fusaria are root-rotting organisms, Kaufman considers that the use of these chemicals may prove beneficial not only in weed control but also through their effect on the soil microbial population.

PROPAZINE AND PROMETON

Mixed with various soils of pH 5 - 7,8 and humus contents of 0.03 - 0.175% at rates equivalent to 12 kg/ha and incubated at 28°C for 15 days, neither of the two herbicides has any effect on CO_2 output or total micro-flora population (including aerobic nitrogen fixing, ammonifying, nitrifying, denitrifying, aerobic, cellulytic and amylolytic bacteria. Even 250 kg/ha has no apparent effect (Pochon et al 1960).

MISCELLANEOUS

(a) Amino-triazole (3/amino-1,2,4-triazole).
Active on many plants at low doses entering through root and foliage and readily translocated. Interferes with chlorophyll production. Dose 4 - 8 lb per acre.

AMINO-TRIAZOLE

Chandra (1964) has found that 8 lb per acre added to samples of soil in the greenhouse inhibits nitrification for about 8 weeks but some nitrification occurs subsequently suggesting that the toxic effect is decreasing. At 80 lb per acre the effect was noticeable for about 24 weeks. There was still a decrease in the number of fungi and bacteria four weeks after treatment but there was no effect after 20 weeks. In the field residual effects were longer but had gone by 52 weeks. A repeat application 56 weeks after the initial treatment showed an increased tolerance as nitrification proceeded much more rapidly than after the first application and Chandra suggests that repeated annual applications of the herbicide would have less residual effect than the initial application.

Guerin-Dumartrait (1960) has looked at the effect of amino-triazole at low concentrations ($5 - 50 \times 10^{-6}$) on the growth and pigmentation of the unicellular organism Chlorella pyrenoidosa. He found that it inhibits cell division and causes cellular hypertrophy. There was a reduction in the chlorophyll and carotinoid content and respiration was increased.

(b) Endothal (disodium 7-oxabicyclo (2,2,1)heptane-2,3-dicarboxylate)
Soil applied pre-emergence herbicides. Applied as a mixture 4:3 ratio with propham, the dose depending on the soil type.
(c) Allyl alcohol.

ENDOTHAL

Jensen (1964a) has found that doses of endothal about two to five hundred times the amounts applied in practice did not appear to influence the gross respiration of the micro-flora of the soil.

ALLYL ALCOHOL

The addition of allyl alcohol to soil causes a temporary inhibition of CO_2 evolution which can be overcome by the addition of cell suspensions of Pseudomonas fluorescens or Nocardia corallina both of which are able to use allyl alcohol as a nutrient (Jensen 1961).

CONCLUSIONS

Possibly one of the most satisfactory results of the investigations so far is that no herbicide tested has more than a transitory effect on the total soil micro-flora.

In many cases this is probably because some micro-organisms are able to decompose the herbicide. Corynebacterium simplex, a common soil microbe can utilise DNOC as a sole source of carbon and nitrogen. Other species as well as some Arthrobacter, Achromobacter, Bacterium, Pseudomonas and representatives of the actinomycetes decompose 2,4-D and related compounds. Dalapon, monuron, DNOC and other related herbicides can be used as energy sources by many soil micro-organisms. Chlorine substituents favour attack by Corynebacterium and other gram-positive organisms. Carbamyl, cyano or nitro-groups favour attack by gram-negative bacteria, especially Pseudomonas. Of the moulds, some species of Acrostalagmus, Aspergillus, Trichoderma and others have been shown to attack 2,4-D and similar compounds (Bollen 1962). In some cases however even where the herbicide is relatively persistent (e.g. simazine) it is non-toxic to the micro-flora.

It should be noted however that only a fraction of the herbicides in common use have actually been tested against micro-organisms. It should not be assumed that because those that have been tested are harmless that it follows that all are harmless.

It appears that not much work has been done in combinations of herbicides for synergistic effects. Kaufman and Sheets (1965) have shown that dalapon is more persistent in soil when applied in combination with amitrole. CIPC is more resistent in soil treated with the insecticide carbaryl and whilst fenac at 300 ppm strongly inhibits Nitrobacter, in combination with dalapon at 100 ppm the toxicity is reduced (Bollen 1962). These are important findings and these investigations should be extended.

In some cases (e.g. dalapon and DNOC) addition of herbicide to the soil leads to a marked stimulation of growth of micro-organisms. In the case of dalapon this is probably because the organisms can utilise it as a carbon source. This does not appear to hold for DNOC since the amounts of carbon dioxide that would arise from such metabolised DNOC would be much less than the observed amount (Jensen 1964). A number of authors have noted that at low concentrations some herbicides stimulate the growth of micro-organisms and use could possibly be made of this fact in processes e.g. yeast production, where increase in growth is desirable.

It appears that some of the herbicides may be selective in their action, some micro-organisms being knocked out, other unaffected and still others stimulated. The paper by Kaufman (1964) is an interesting one in which he finds that both atrazine and simazine stimulate certain fungi that are antagonistic to pathogenic fusaria.

The findings by Mitzkovski (1959) that although 2,4-D had little effect on the soil micro-flora it did adversely affect the epiphytal micro-organisms is probably related to the well known protective power of the soil and also that the concentration of herbicide on the leaf is probably much higher than that in the soil. This finding could have important consequences in the field of plant pathology. A number of papers have been quoted (Fletcher 1960) showing that herbicides can affect the course of certain plant diseases and that the storage life of certain fruits can be prolonged by treating them or their wrapping papers with, for example, 2.4-D. Shennan (unpublished) has found that 500 ppm MCPB did show some evidence of chemotherapeutic activity against Clover Leaf Spot (Pseudopeziza trifolii). If it could be shown that selective herbicides, as well as killing weeds could also control leaf and stem diseases in the crop then their sphere of action could obviously be much extended.

Although a great many papers have been published on the effect of herbicides on micro-organisms, remarkably little has been done on the investigation of their modes of action at the biochemical level. This may well be because relatively high concentrations are required to produce an effect. It would seem however that such investigations can be rewarding not only in their own right but also as giving a lead into their effects on higher plants. The work done on MCPA and MCPB is an example of this approach.

It is often assumed that once an organism has become adapted to a particular herbicide then that organism will, in the presence of continuous additives of the herbicide, multiply more rapidly because of the lack of competition from its more susceptible fellows. This may not however be the case. Experiments carried out by Dean and Law (1964) showed that the growth rate of Aerobacter aerogenes which had remained constant over some 25 sub-cultures in the presence of 2,4-D began to decrease over the succeeding 91 sub-cultures providing evidence of the limited extent to which adaptation to 2,4-D occurred.

References

ASCHEMAN, R.E. (1963) The fate of Amiben (3-amino-2,5-dichlorobenzoic acid) in plants and soil. Diss. Abstr. 24, (1), 14-15.

BOLLEN, W.B. (1962) Herbicides and soil micro-organisms. Proc. 19th Western Weed Control Conf. 48-50.

BURNSIDE, O.C. (1959) The influence of environmental factors on the phytotoxicity and dissipation of simazine. Ph.D. Thesis Univ. Minnesota, pp. 114.

BURNSIDE, O.C., SCHMIDT, E.L., & BEHRENS, R. (1961) Dissipation of simazine from the soil. Weeds 9, (3), 477-84.

CHANDRA, P., FURTICK, W.R., & BOLLEN, W.B. (1960) The effect of four herbicides on micro-organisms in nine Oregon soils. Weeds 8, (4), 589-98.

CHANDRA, P. (1964) Herbicidal effects on certain soil microbial activities in some known soils of Saskatchewan. Weed Res. 4, (1), 54-63.

COUKE, C.T., & ROBINSON, J.B. (1960) Herbicides and the soil population. Proc. 7th ann. Meet. agric. Pest Tech. Soc. Canada, 69-72.

DEAN, A.C.R., & LAW, H.S. (1964) The action of 2,4-dichlorophenoxyacetic acid on Bacterium lactis aerogenes (Aerobacter aerogenes). Ann. Bot. 28, (112), 703-10.

DURKHANIN, A.A., & KOLOSOVA, A.A. (1962) (Effect of 2,4-D on the nitrate phosphate nutrient regime of sandy and chernozemic soils.) Trudy vsesoyuz nauch-issled Inst. Vdober Agropochvoved (39), 226-32.

ENO, C.F. (1962) The effect of simazine and atrazine on certain of the soil micro-flora and their metabolic processes. Proc. Soil Crop Sci. Soc. Fla., 22, 49-56.

FERNANDES, C.S. (1957) Action of 2,4-D and TCA on nitrification of ammonia. Univ. rural Pernambuco Comm. tech., 4, pp. 14.

FLETCHER, W.W. (1960) The effect of herbicides on soil micro-organisms. Proc. Br. Weed Control Comm. Symp., Herbicides and the Soil. 20-62.

GRAMLICH, J.V., COUCH, R.W., SIKKA, H.C., DAVIS, D.E., & FUNDERBURK, H.H. (1964) Preliminary report on atrazine metabolism by micro-organisms. Proc. 17th Sthe Weed Conf., 356.

GUERIN-DUMARTRAIT, E. (1960) Action du 3-amino 1, 2, 4 triazol sur la croissance, la teneur en pigments et les intensities photosynthetique et respiratoire de Chlorella pyrenoidosa Chick. C.R. Acad. Sci., Paris, 250, (18), 3044-6.

GUILLEMAT, J. (1960) Interactions entre la simazine et la mycoflore du sol. C.R. Acad. Sci., Paris, 250, (7), 1343-4.

GUILLEMAT, J., CHARPENTIER, M., TARDIEUX, P., & POCHON, J. (1960) Interactions entre une chloro-amino traizine herbicide et la microflora fongigue et bacterienne du sol. Ann. Epiphyt., 11, (3), 26-95.

ILLYIN, A.M. (1961) (Effect of herbicide 2,4-D on soil miero-organisms) Mikrobiologiya, 30, 1050-1.

JENSEN, H.L. (1961) (Biological decomposition of herbicides in the soil. II Allyl alcohol) Tidsskift for Planteavl. v.65, 185-198.

JENSEN, H.L. (1964a) (Biological decomposition of herbicides in the soil. III Endothal) Tidsskrift for Planteavl. v.67, 553-571.

JENSEN, H.L. (1964b) (Influence of dinitro-ortho-cresol (DNOC) dinitrobutyl-phenol and 2,4-dinitrophenol (DNP) on soil respiration. Tidsskrift for Pleanteavl. v.67:863-874.

JUNG, J. (1964) (The effect of Pyramin on soil respiration and nitrification.) Wiss. Aussprache über chem Unkrautbekämpfung in Zuckerrüben mit Pyramin, Ludwigshafen am Rhein, 85-91.

KAUFMAN, D.D. (1964) Effect of s-Triazine and phenylurea herbicides on soil fungi in corn and soybean cropped soils. Phytopathology, 54, 897.

KAUFMAN, D.D., & SHEETS, T.J. (1965) Microbial decomposition of pesticide combinations. Agronomy Abstracts 57:85.

KLYUCHNIKOV, L. Yu., PETROVA, A.N., & POLESKI, Yu.A. (1964) (Effect of simazine and atrazine on micro-flora of sandy soil). Mikrobiologiya, 33, 992-6.

KIRKWOOD, R.C., ROBERTSON, M.M., & SMITH, J.E. (1966) Differential absorption as a factor influencing the selective toxicity of MCPA and MCPB. Proc. Symposium Use of Isotopes in Weed Res. Vienna, 1965, 47-56.

LENHARD, G. (1959) The effects of 2,4-D on certain physiological aspects of soil micro-organisms. S. Afric. J. agric. Sci., 2, (4), 487-97.

MAGEE, L.A., & COLMER, A.R. (1960) Effect of dalapon on the microflora of Mhoon soil. Sugar Bull., 38, 242-5.

MASKTAKOV, S.M., GURINOVICH, E.S., SIMENKO, T.G., & KABAILOVA, I.V. (1962) (Effect of herbicides on micro-flora soil). Mikrobiologiya, 31, 85-9.

MITZKOVSKI, M. (1959) (Contribution to the knowledge of the influence of the herbicides 2,4-D and MCPA on the soil and epiphytal micro-flora of sprayed pests and plants). Agrochemiga (8), 58-63.

PANTOS, G.Y., et al (1962) (The effect of field applications of herbicides on species and groups of the soil micro-flora and micro-fauna and on mycorrhizae with some questions on the biological inactivation of herbicides). Erdeszettud. Közl., Sopron., (2), 3-57.

POCHON, J., TARDIEUX, P., & CHARPENTIER, M. (1960) Recherches sur les interactions entre les aminotriazines herbicides et la micro-flora bacterienne tellurique. C.R. Acad. Sci., Paris, 250, (8), 1555-6.

POMMER, E.H. (1964) (The effect of Pyramin on soil fungi) Wiss. Aussprache über chem Unkrautbekämpfung in Zuckerrüben mit Pyramin, Ludwigshafen am Rhein, 92-4.

RAUD, G., TYSSET, C., & VACHER, B. (1959) Recherches sur les proprietes algostatiques de la 3-p-chlorophenyl 1-1 dimethyl uree (monuron, CMU) en microbiologie du sol. Ann. Inst. Pasteur, 96, (2), 242-4.

SHENNAN, J.L., & FLETCHER, W.W. (1965) The growth in vitro of micro-organisms in the presence of substituted phenoxyacetic and phenoxybutyric acids. Weed Res., 5, (3), 266-274.

SHKLYAR, M.S., VOEVODIN, A.V., & MARKOVA, V.G. (1959) (The effect of 2,4-D and chloropropham on the development of some soil micro-organisms.) Bull Nauchno-Tekh. Inf. Selsk. Mikrobiol (4), 14. (Russ.).

SHKLYAR, M.Z., VOEVODIN, A.V., & BESHANOV, A.V. (1961) (Effect on soil micro-flora of herbicides applied before the emergence of crop seedlings). Agrobiologiya (2), 222-5.

SMITH, J.E., & SHENNAN, J.L. (1966) The effect of substituted phenoxyacetic and phenoxybutyric acids on the growth and respiration of Aspergillus niger. J. gen. Microbiol., 42, 293.

SMITH, J.E., & FLETCHER, W.W. (1964) 3:5 dihalogeno-4-hydroxybenzonitriles and soil micro-organisms. Hort. Res. 4, (1), 60-62.

STEINBRENNEL, K., NAGLITSCH, F., & SCHLICHT, I. (1960) Der Ein fluss der Herbizide Simazin and W6658 auf die. Bodenmikroorganismen und die Bodenfauna. Albrecht-Thaer-Archiv., 8, 611-31.

VIRACH, A. (1962) Combaterea Burvienelor cu Ajutorul Erbicidelor: referate sustinue la Consfatuirea Internationata, Bucharest, 195-9.

VIRAG, A. (1959) (The effect of chemical weedkillers on some microscopic fungi). Agrartud. Egyet mez ögazd Kar. Közl, 343-56.

VODERBERG, K. (1961) AbhÄngigkeit der HerbizidWirkung auf Bodenmikroorganismen vom NÄhrsubstrat. NachrBl. dtsch. PflSchDienSt., Berl., 15, (2), 21-3.

VOROBEV, F.K., & ABUEVA, A.A., (1960) (Effect of the trimethanolamine salt of 2,4-D on nitrogen metabolism) Dokl. s-kh.Akad. Timiryazeva, 52, 347-53.

WOODFORD, E.K., & EVANS, S.A. (Eds.) (1965) Weed Control Handbook, Blackwell Scientific Publications.